BEHAVIOR OF LIGHTWEIGHT WALL PANELS AGAINST BLAST

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ABSTRACT

On April-11-1994, a full scale test was conducted, to examine the behavior of light weight wall panels against surface burst of 830 Kg. of T.N.T.
The wall panels were positioned in four different distances from the center of the explosion (c.o.e).
Each wall contained three different materials: corrugated asbestos-cement sheets, corrugated fiberglass sheets and cold form light-gage metal.
High speed cameras were positioned to evaluate initial velocity of fragments from wall panels.
The paper describes the test and it's results, secondary fragments collection data, fragments range prediction versus actual observed range and recommendation as to the choice of the material to be used in future constructions.

INTRODUCTION

In TAAS -Israel Industries plants, buildings should be sited according to the DoD 6055-STD "Ammunition and Explosives Safety Standard"(1). These standards give criteria for determining the distance required to provide protection from blast pressure, hazardous fragments and thermal loads. These rules apply not only for safety distances nearby inhabitant areas, but also for personnel in TAAS's plants that don't deal with explosive materials. The default fragments safety distance is 1250 feet, which govern the blast pressure safety distance up to a quantity of 30000 lb.'s of class/division 1.1 explosives. This distance should be taken unless it can be shown by analysis or tests that hazardous fragment will be thrown to shorter distance.

In TAAS, many structures, where explosives are handled or stored, are made of lightweight

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components such as corrugated metal, asbestos-cement sheets or fiberglass sheets. Therefore, the behavior of wall panels made of those materials is of great interest to us.
Not only fragmentation distance from an explosion in, or nearby such light-weight structures is important. The knowledge of the behavior of those cladding elements in structures that are sited in the intraline distance, and the barricaded intraline distance, is important to us as well. Therefore a test was conducted to examine this behavior, and to study fragment's characteristics.

GENERAL DISCUSSION

Fragments and debris dispersal from an explosion is rather complicated. First, the transient forces that act on an element must be considered. Then, we have to decide about the size and the characteristic (chunky, flat, etc.) of the fragment that will be accelerated and it's launching angle. The next stage is the flight, which can be integrated from the differential equation of motion, but should take into account factors like drag, lift forces and spin.
When the fragment hits the ground, it usually ricochets or roles.
The interaction of blast waves with solid object includes three phases as the wave passes over the object those are shown in figure (2-246) in the manual (2).
Based on the assumptions for unconstrained secondary fragments as follows :

1) the object behaves as a rigid body.
2) the blast energy do not absorbed in breaking or deflecting the object.

The manual offers a method of calculating the initial velocity and the specific impulse imparted to the object. But this is good for standoff distance to explosive radii ratio less then 5.07, which is usually not our case.
The manual suggests that for values greater then this, the impulse may be approximated by using the normal reflected impulse.

The values for reflected impulse given in the manual refer to blast reflected on a rigid infinite surface, and it may sometimes be 20 times greater then the incident impulse. Thus, using the value of the reflected impulse, may result in overestimating of the flight distance. This, will cause increasing of separation distance or, decreasing the amount of explosives.

The method for predicting fragments' range, given in the manual, uses only 2D model, taking into account the drag forces and neglecting lift forces and spin. Spinning of a flying object may stabilize the motion and thus, ignoring it, may result in underestimating the flight distance.

Neglecting the ricochet or the roll after hitting the ground, may also result in underestimation of the range, but, on the other hand, ignoring the fact that some energy is consumed in tearing the fragment from its place and deforming it, and this may offset those phenomena (spin and ricochet). From the above , it seemed that a test to be made was a "must".

It should be mentioned that at the 25 th' explosives safety seminar, a model for prediction of debris hazard (DIPRE) was presented (3), in this paper it was recommended as follows:
"Additional tests and analysis need to be conducted for corrugated metal panel surfaces and

other lightweight components since the model bases its current analysis of this components on two validation tests and data collected from limited accident data bases."

"The effects of close-in and far-range loading on lightweight components need to be studied in much more detail, as the loading has been shown to greatly affect the manner in which these components fail and the size of the resultant debris. "

TEST DESCRIPTION

On April -11- 1994, a full scale test took place. 830 Kg' of T.N.T caste in three barrels,were detonated on the ground.
Around the center of the explosion, (c.o.e), four wall panels were positioned in four different distances.
Each wall, contained three different materials

1. Corrugated asbestos-cement sheets, which weight about 13 kg/sq.m'
2. Corrugated fiberglass sheets, which weight about 1.5 kg/sq.m'.
3. Cold form light-gage metal, which weight about 5.5 kg/sq.m'.

Each wall panel was 3.00 m' high and 4.00 m' wide.

The cladding materials were attached to purlins (80 m'm channels),that were connected to steel columns. In order to avoid turn ove , the wall construction was anchored to the ground with 1 m' angles that were driven into the ground by hammering .

The layout of the test arrangement is shown in figure (1). The nearest wall was located 10.0 m' from c.o.e., and the cladding materials were lying on the outer face of the wall (to simulate an explosion within a donor structure). The second wall was positioned 20.0 m' from the c.o.e.(to simulate an explosion near structure within the donor area). Another wall was located at a distance of 35.0 m' from c.o.e.,which is the barricaded intraline distance from this amount of T.N.T. As we well know, barricades may prevent hazard from high speed fragments, but the blast attenuation is insignificant. In order to examine the behavior of lightweight wall of a structure sited at the intraline distance, the last wall was positioned at the distance of about 67.5 m' . The wall panels can be seen in the pictures at the end of this paper.

At a distance of about 200 m', two high speed cameras were positioned, so that initial velocities of fragments from the wall panels could be evaluated. Four pressure gages were put near, and in front of the 10.0 and 20.0 m' walls, this, in order to check the pressure in the free field (incident) and the pressure in the reflected zone. The pressure gages can be seen in the pictures at the end of the paper.

FIGURE 1. LAYOUT OF TEST ARRANGEMENT

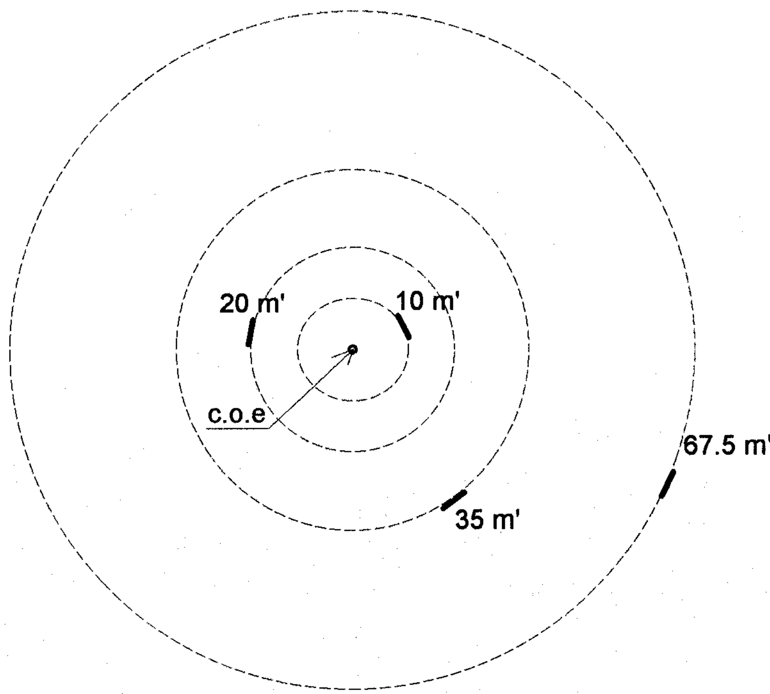


figure 1. layout of test arrangement

TEST RESULTS

The wall panel 10.0 m' from c.o.e.

The wall was totally destroyed, the steel construction elements were thrown as follows:
One column was thrown to a distance of 21 m'.
Another column landed 38 m'. from its original place.
The lower beam was found 53 m' from the wall, and the purlin reached the distance of 27 m'. An anchoring angle was pulled out off the ground and landed 9 m'. from there.
The asbestos cement sheets were fractured into hundreds of pieces ranging between 26 and 100 m' from the original place of the wall.
Figure (2), shows the number of fragments per distance interval. Figure (3) shows the distribution of the fragments' size.
We should note here that only about 1/3 of the original area of the sheets were found in the fragments collection process. Very small fragments couldn't be spotted and we can say that about 2/3 of the sheets turned to "dust".

Figure 2. : Asbestos-cement fragments distribution over the range

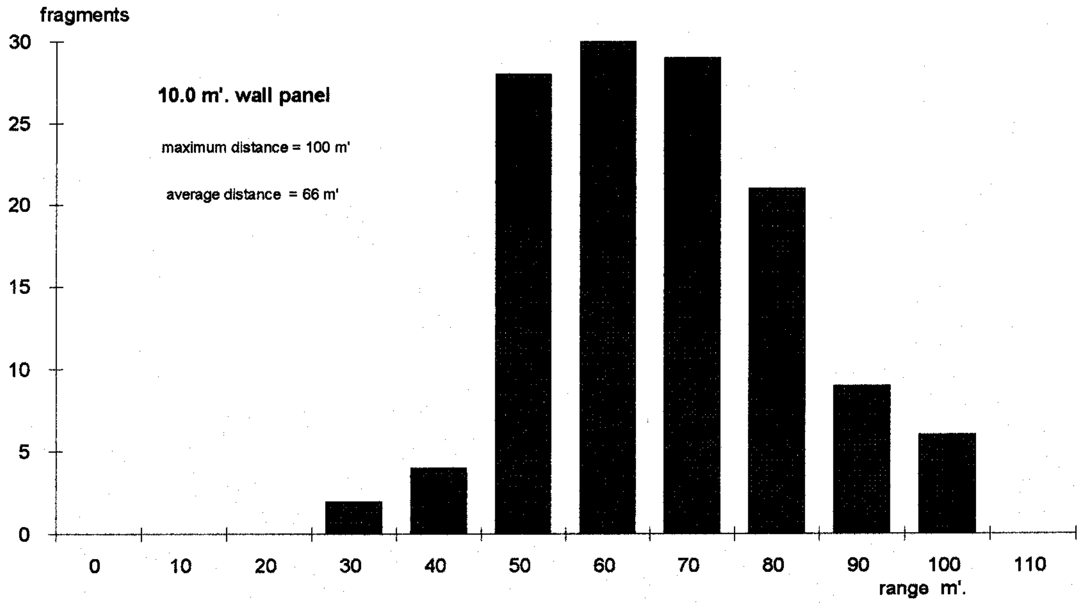


Figure 2. : Asbestos-cement fragments distribution over the range

Figure 3. : Distribution of asbestos-cement fragments' size.

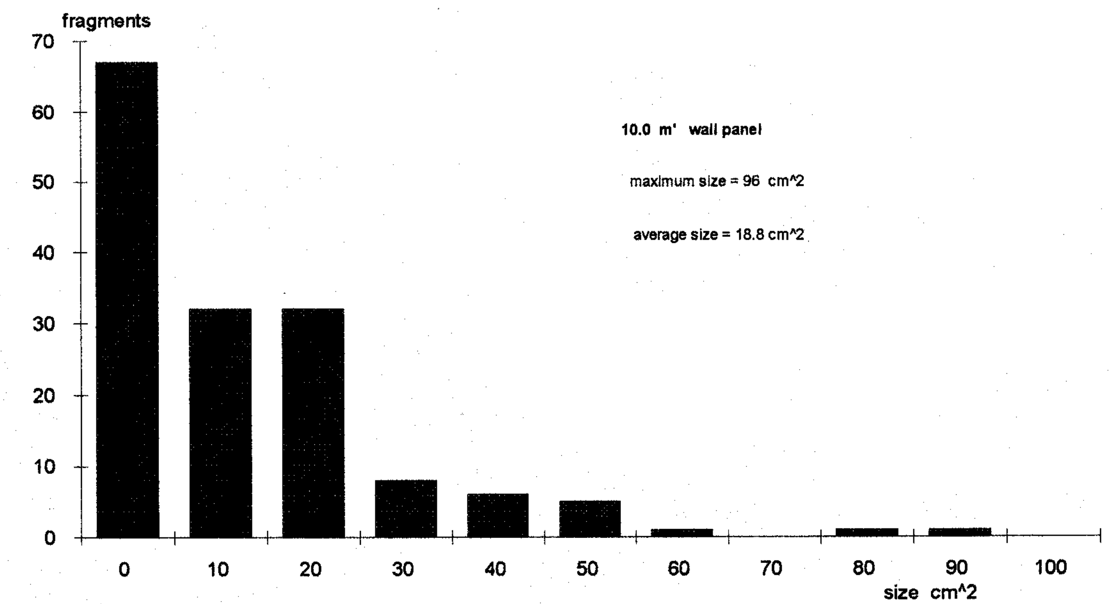


Figure 3. : Distribution of asbestos-cement fragments' size.

Figures (4), (5), show the same statistic data but for the fiberglass sheets.
It should be noted that many small fiberglass fragments were sucked backwards and were scattered between the original place of the wall, and the c.o.e.
The furthest fiberglass piece landed 48 m' from the wall.

Figure 4. : fiberglass fragments distribution over the range.

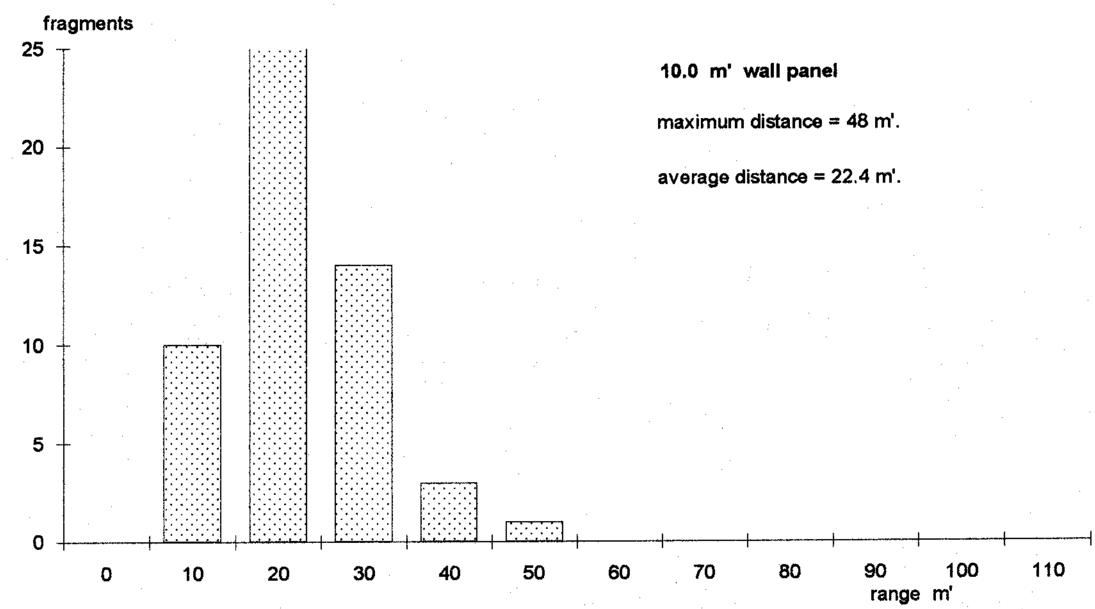


Figure 4. : fiberglass fragments distribution over the range.

Figure 5. : Distribution of fiberglass fragments' size.

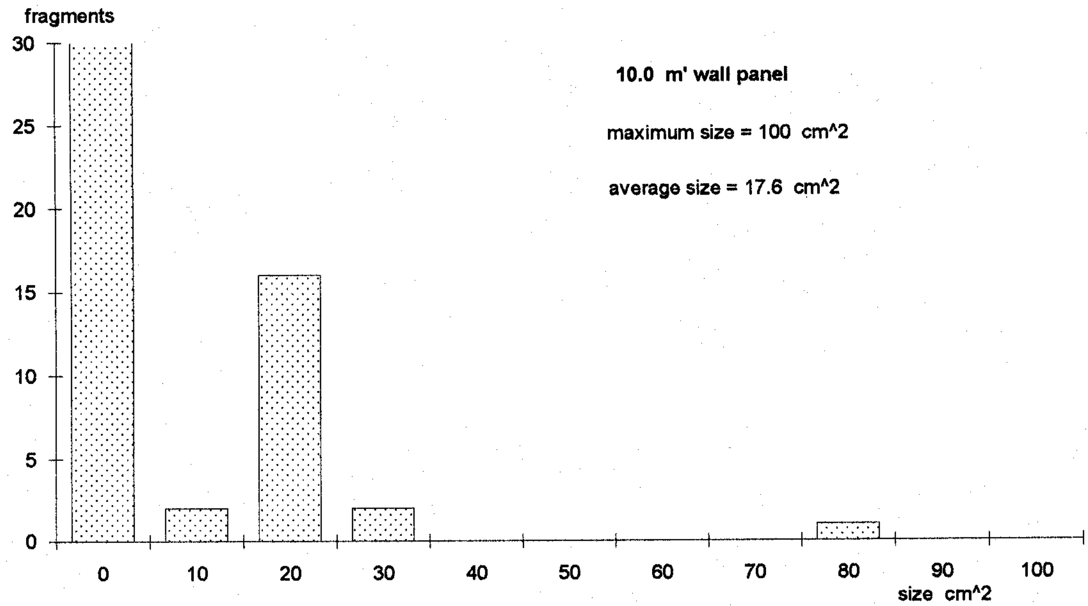


Figure 5. : Distribution of fiberglass fragments' size.

The metal sheet was shattered to 50 pieces. The big fragments were twisted and deformed in a way that it was impossible to measure their exact size, and only a rough estimation was made.
Fragment collection data for the metal sheet is illustrated in figures (6), (7).
The pressure gages were ruined , and as a result , there were no records at all.
No practice data could be retrieved from the high speed camera, thus, because of the illumination from the fire ball, and the only two things that could be seen are a metal piece that traveled at a velocity of 15 m'/sec. and the anchoring angle that was flying at a speed of 10 m'./sec. .

The wall panel 20.0 m' from c.o.e.
The main steel construction remained in its original position , except of the middle purlin that was disconnected , and was found near the wall . The asbestos-cement sheets were fractured into hundreds of small pieces ranging between 11 and 64 m'. from the wall. Figure (8) shows the number of fragments per distance interval. Figure (9) shows the distribution of the fragments' size. We should note that summation of fragments' size equals the original sheets area, meaning that all the fragments were found in the collection process.

Figure 6. : metal fragments distribution over the range.

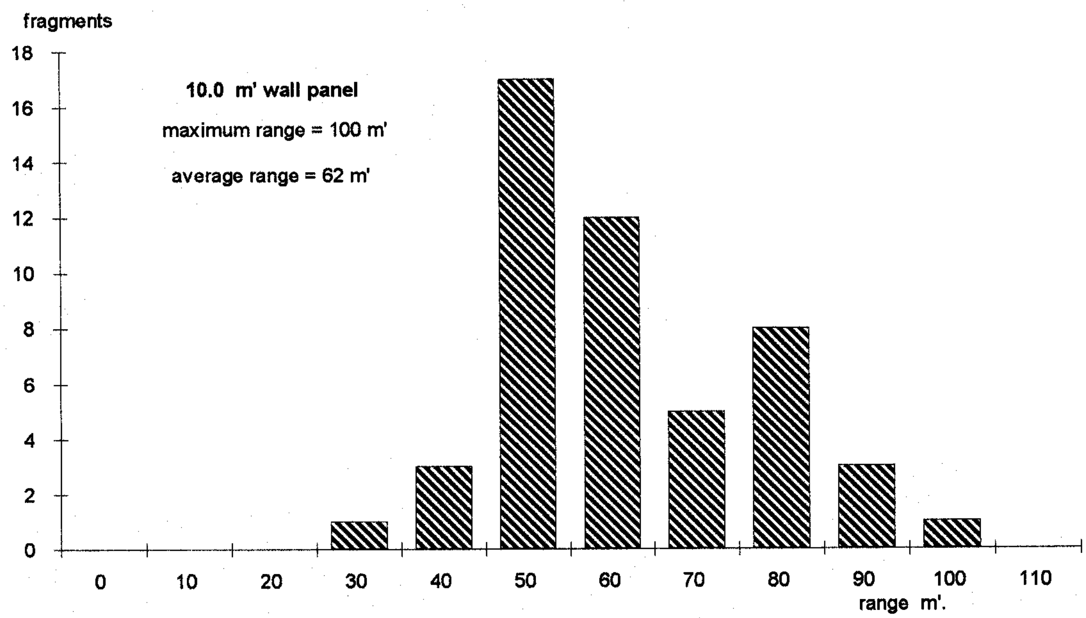


Figure 6. : metal fragments distribution over the range.

Figure 7. : Distribution of metal fragments' size.

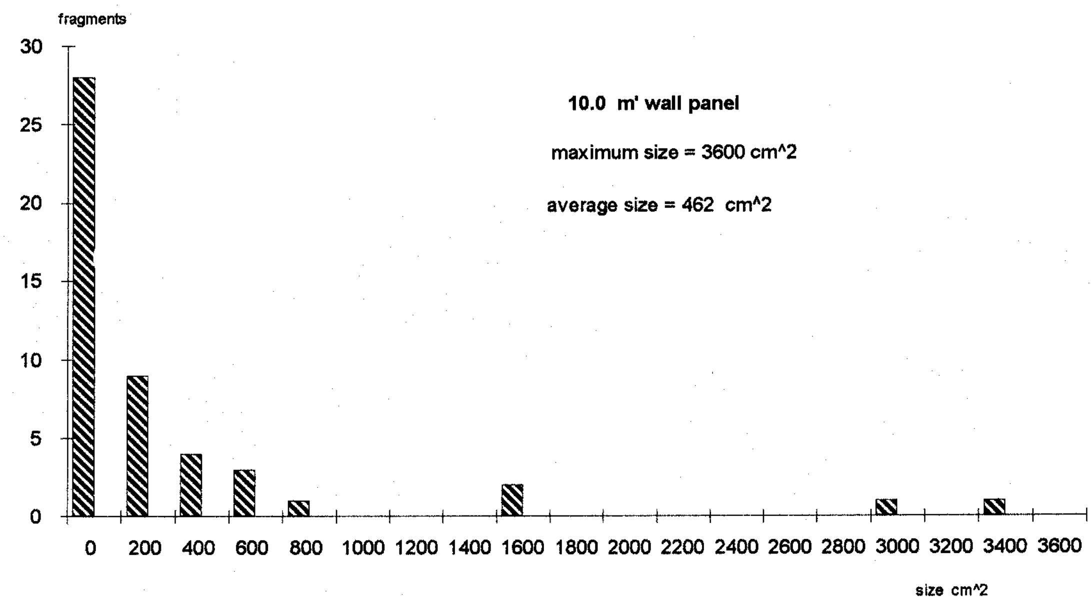


Figure 7. : Distribution of metal fragments' size.

Fiberglass pieces were found from 10 m'. up to 25 m' from the wall panel.
Figures (10), (11), show the same statistic data for the fiberglass sheets.
The metal sheet panel flew as one twisted piece and was found 27 m' from its original location.
From data obtained by developing of the high speed camera's film , we could evaluate the initial velocity of the fragments to be between 50 and 140 m./sec.,with launching angle of less then 30 deg..

Figure 8. : Asbestos-cement fragments distribution over the range

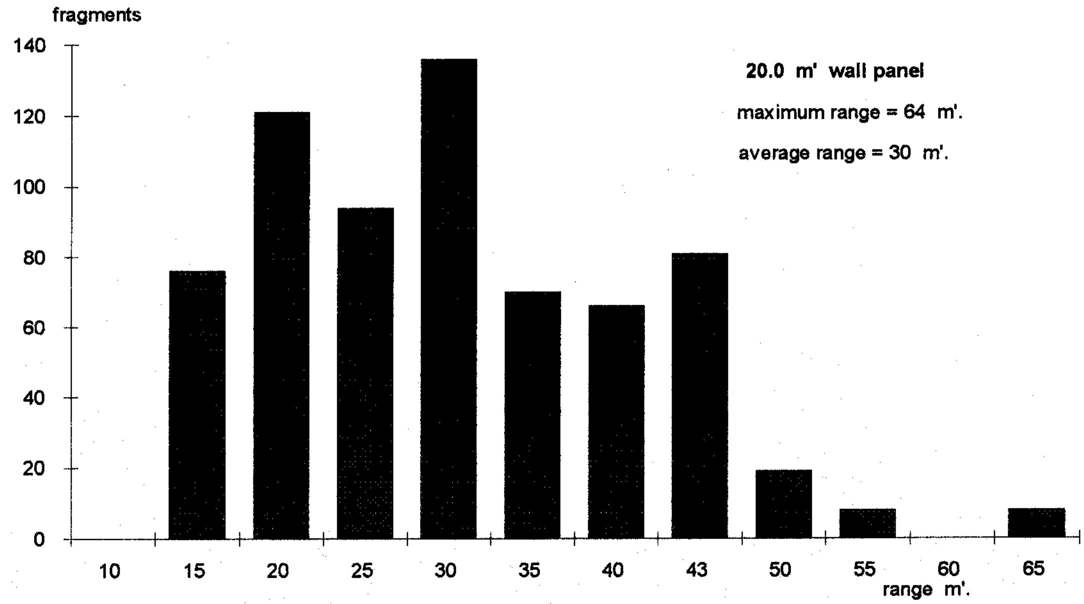


Figure 8. : Asbestos-cement fragments distribution over the range

Figure 9. : Distribution of asbestos-cement fragments' size.

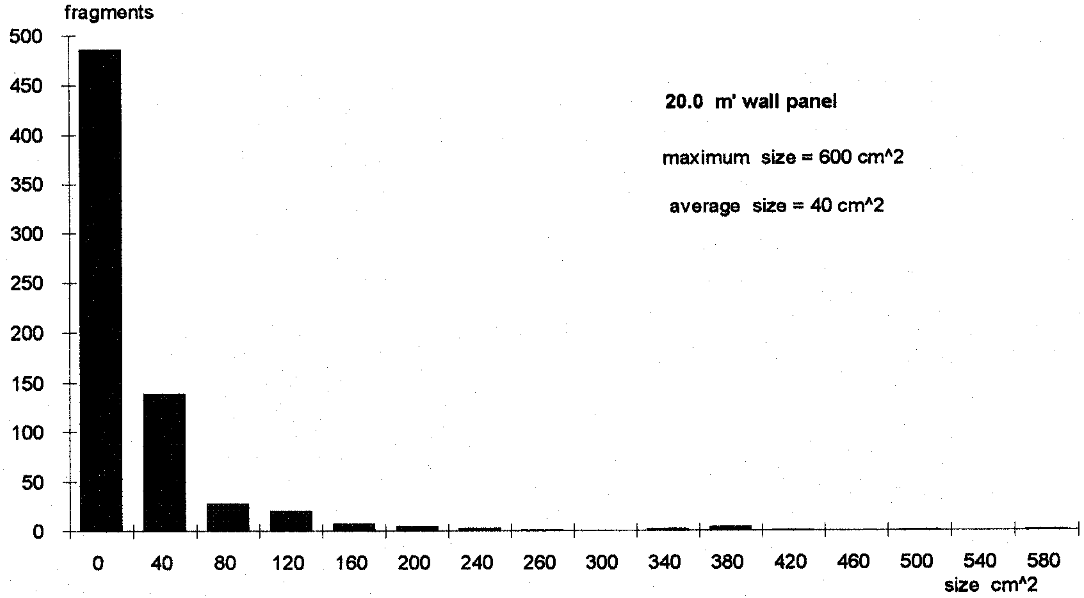


Figure 9. : Distribution of asbestos-cement fragments' size.

Figure 10. : fiberglass fragments distribution over the range.

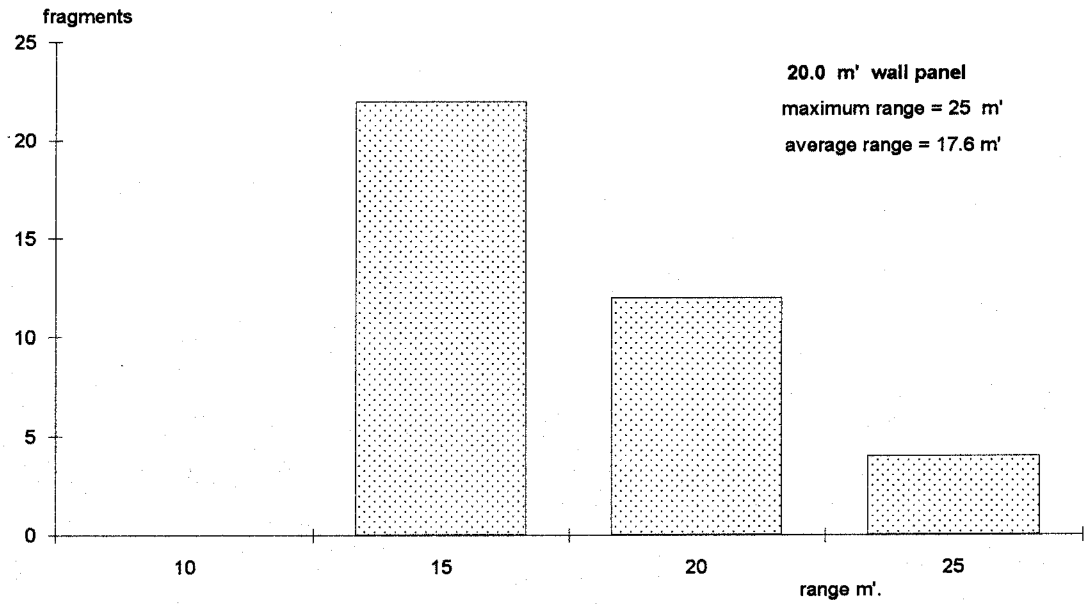


Figure 10. : fiberglass fragments distribution over the range.

Figure 11. : Distribution of fiberglass fragments' size.

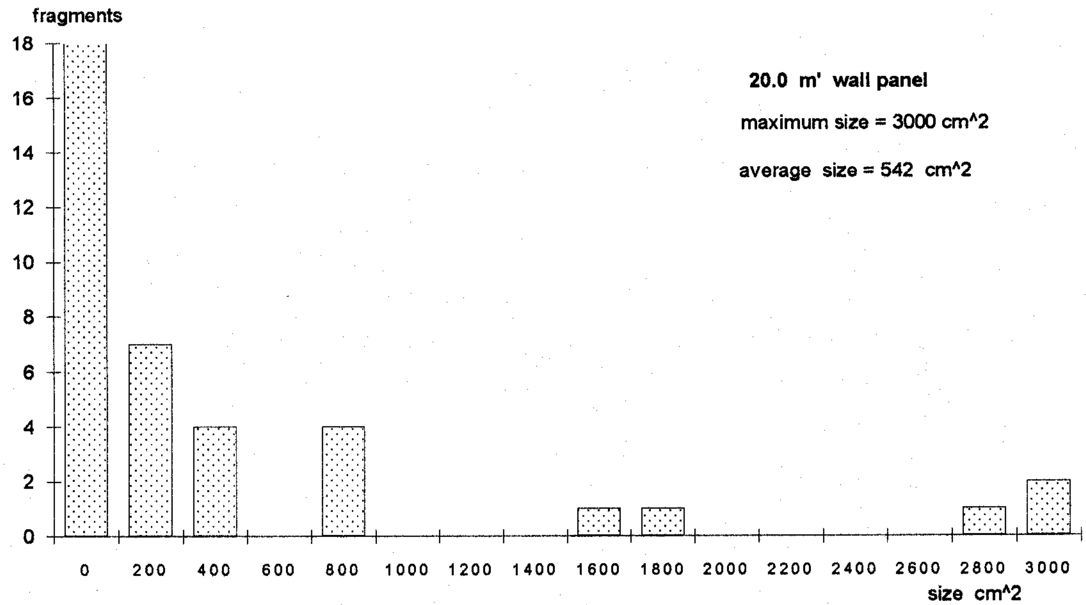


Figure 11. : Distribution of fiberglass fragments' size.

The wall panel 35.0 m' from c.o.e.
The wall as a unit was slightly raised , but the main steel construction was not damaged . The purlins suffered large deflection and the lower purlin was disconnected.
Asbestos-cement pieces were scattered from 3 m' up to 33 m' away from the wall.
the furthest fiberglass piece was lying at a distance of 19 m' from the wall and the nearest was found at a distance of 4 m'.
The metal panel was heavily deformed , but it remained hanging on the steel construction.
Figures (12),(13) show the distribution of asbestos-cement and fiberglass fragments respectivly.

Figure 12. : Asbestos-cement fragments distribution over the range

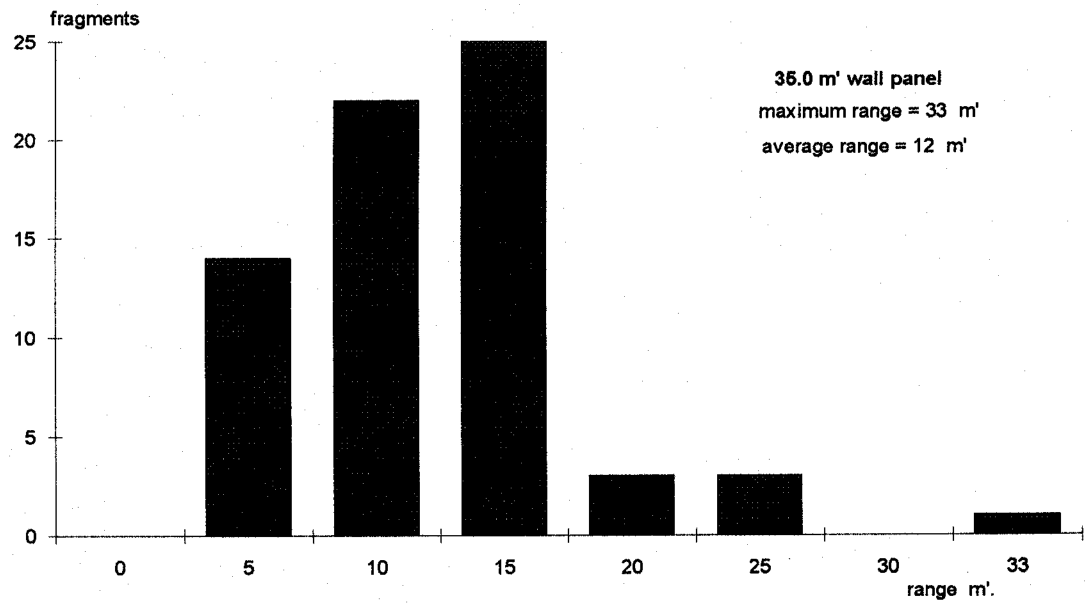


Figure 12. : Asbestos-cement fragments distribution over the range

The wall panel 67.5 m' from c.o.e
The steel construction was not damaged at all. The purlins suffered only minor deflections. The metal panel suffered relatively small deflections. The asbestos-cement sheets were broken into a few large parts, and about half of it still remain hanging on the construction. The furthest piece was lying 8 m' from the wall.
The fiberglass sheet was broken also into large pieces that fell to the ground near the wall.

Figure 13. : fiberglass fragments distribution over the range.

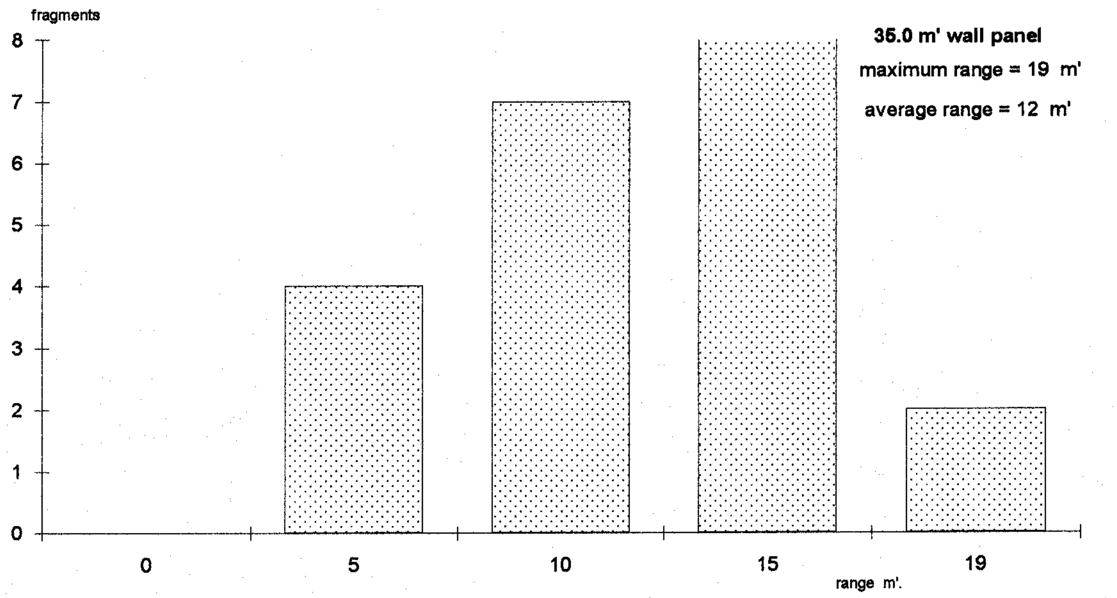


Figure 13. : fiberglass fragments distribution over the range.

RANGE CALCULATIONS

Let's consider range prediction according to the manual (2) , for the asbestos-cement sheets of the 20 m' wall panel .(the actual distance measured before the explosion was 20.7 m' from c.o.e .)
From the manual we get the reflected impulse from hemispheric surface burst .

$$Ir = 440 \text{ psi-msec}$$

The furthest asbestos-cement piece , landed 64 m' (210 feet) from the wall and its dimensions were 13 x 6 cm'.
Thus, the fragment's weight is :

$$W = 0.13 * 0.06 * 13 = 0.1 \text{ kg} = 0.223 \text{ lb'}$$

The mass of the fragment is :

$$M = W / g = 0.223 / (32.2 * 12 * 10^{-6}) = 577.12 \text{ lb-msec/in}$$

The presented area is :

$$Ad = 12 \text{ in2}$$

According to table 2-8 of the manual , the drag coefficient for a disc , face on is: Cd = 1.17 but , on the other hand , since the fragment is corrugated , a lower coefficient should be taken. Since we know (from the high speed camera) that the maximum initial velocity was 140 m' / sec , we are able to find the drag coefficient , by trail and error , to be around:

Cd = 0.97

Thus , the non-dimensional range is :

EQUATION

$$12 * \rho o * Cd * Ad * R / M = 12 * 0.115 * 0.97 * 12 * 210 / 77.12 = 5.85$$

Out of figure 2-252 we get the non-dimensional velocity :

EQUATION

$$12 * \rho o * Cd * Ad * Vo^2 / M * g = 180$$

from which the initial velocity is calculated to be :

Vo= 456 feet / sec = 139 m' / sec .

By equating the impulse with the momentum we get :

I = M * Vo = 577.12 * 12 * 456 / 1000 = 3158 lb - msec

and dividing by the fragment's size we get the specific impulse :

i = 3158 / 12 = 263 psi - msec

which is about 60 % of the reflected impulse.

From fragments' collection data , the furthest piece of asbestos-cement was found 100 m' from the wall panel that was located 10 m' from the c.o.e. (the precise distance measured before the

explosion was 9.8 m') . the dimensions of the fragment was 6 x 4 cm' .
Doing the same calculations with the same drag coefficient (Cd = 0.97) give us an impulse of 1132 psi-msec which is about 99 % of the reflected impulse .

The furthest fragment from the 35.4 m' wall panel , landed 33 m' from it , and its size was 25 x 6 cm'. Calculating the same way , we get that 72 psi-msec is the impulse that if taken , cause the fragment to fly to that distance. Since the calculated reflected impulse acting on the wall is 235 psi-msec. only , 31 % of it propels the furthest fragment .

The calculated reflected impulse acting on a rigid wall 67.5 m' from a hemisphere surface burst of 830 kg. of T.N.T is 115 psi-msec . Calculating the same way to achieve the unknown impulse that will throw a fragment of asbestos cement with dimensions of 55 x 7 cm' to a distance of 8 m' (test results) yields an impulse of only 20 psi-msec. (about 17 % of the reflected impulse).

figure (14) shows us the reflected , the incident impulse , and the calculated impulses that should be taken in order to comply with the test results , all of these, versus the distance of the wall panels from c.o.e. .

The calculations we made for the asbestos-cement fragments could not be made for the other materials that were tested .The data of the fragments' weight and the impulses for the different distances involved velocities that were out of limits of the graph given in figure (2-252) of the manual (2). But, calculations we made by numeric integration of the differential equation of motion , for the fiberglass fragments , gave a very similar behavior as we see in figure (14) .

Figure (14) : calculated impulses that propel asbestos-cement fragments to maximum distance , from different distances of the wall panels from c.o.e

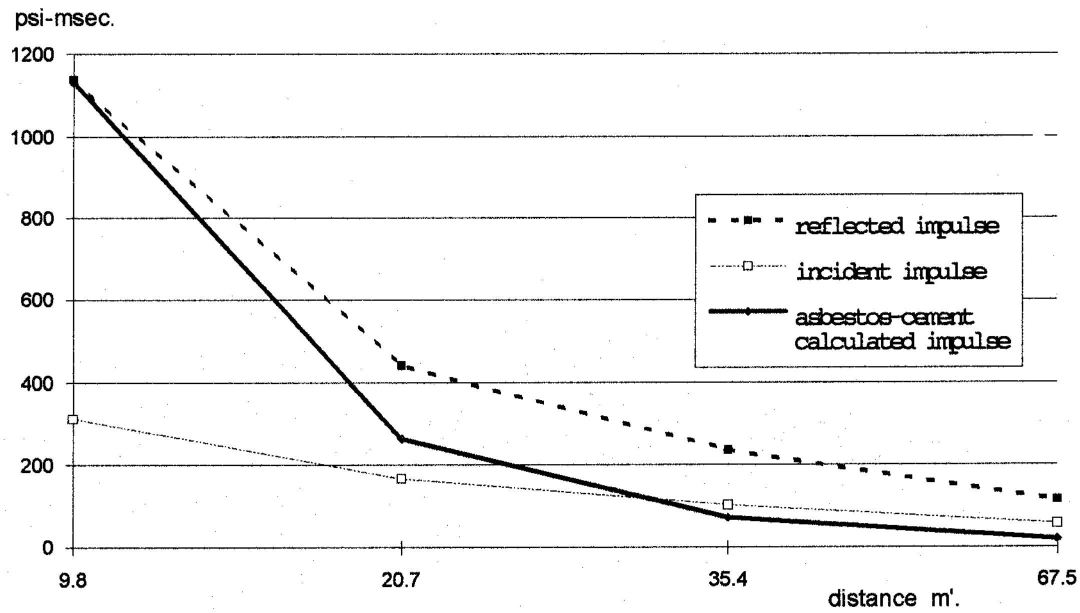


figure (14) : calculated impulses that propel asbestos-cement fragments to maximum distance , from different distances of the wall panels from c.o.e

CONCLUSIONS AND RECOMMENDATIONS

The test that was made , proved that choosing minimum separation distances taken from the DoD standards , may sometimes result in a waste of land, especially , when lightweight wall panels are involved .
Even calculating fragments' range according to the manual (2) , may result in an overestimation of the flight distance .
From test results we can draw some conclusions and make the following statements :

1. The closer the explosion is to the lightweight wall , the smaller the fragments get .

2. Fiberglass sheets shatter into lesser fragments than the asbestos-cement , and they reach around half the distance .

3. The value of the impulse to be taken for calculating initial velocity of the furthest fragment is less then the reflected impulse. As the distance of the wall from the detonation gets larger , the impulse that propels those fragments gets smaller relative to the reflected impulse .

4. No correlation was found between the size of the fragment and its flying distance .

5. Steel construction elements flew (if at all) to much shorter distances than the cladding materials .

As we could see from test results the metal sheet behaves in a much safer manner than the other lightweight materials tested . Near the explosion it shatters to much less fragments , and part of the impulse is absorbed in deforming and twisting the fragments .
In the barricaded intraline distance the metal sheet remained hanging on the construction and it did not turn into fragments , more-ever ,there is a very good possibility that the panel could shield personnel from blast pressure if stayed behind such a wall panl .
Therefore , we can say that using metal sheets instead of the other cladding materials , is highly recommended .

In this paper we did not discuss the hazardous fragment density (more than one fragment per 600 sq. feet) . Which means , that the furthest fragment is not hazardous , and more reduction can be made in the fragment safety distance . Although we can get that information from test results , we decided not to deal with it in order to be on the safe side .
It should be mentioned , that the test was made with only one amount of explosive charge and in order to apply the scaling laws , more testing should be done with different quantities of explosive materials and with different distances .

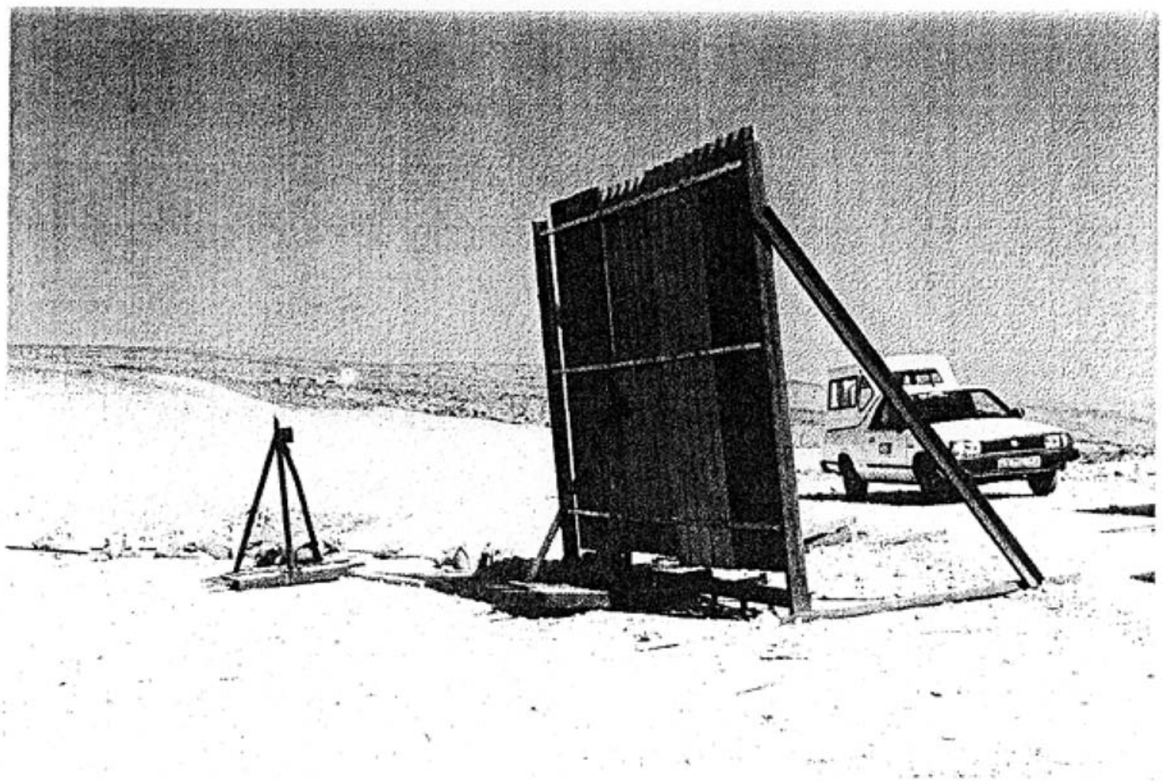
REFERENCES

1. "Department of Defense Ammunition and Explosives Safety Standards ." DoD 6055.9-STD, January 1991

2. "Structures To Resist The Effects of Accidental Explosions."

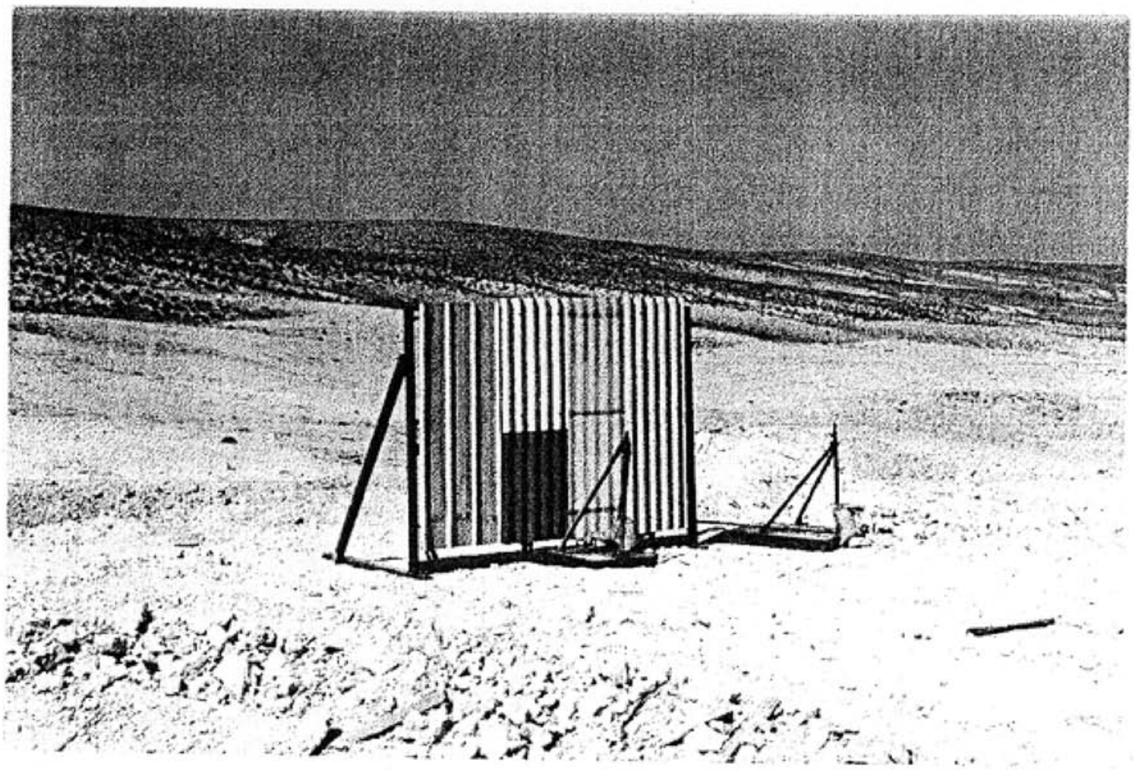
3. "Practical Use of the Building Debris Hazard Prediction Model, (DISPRE)" by Patricia Moseley Bowles , Southwest Research Institute, San Antonio, Texas, USA

PICTURE 1.: WALL PANEL 10M FROM C.O.E.



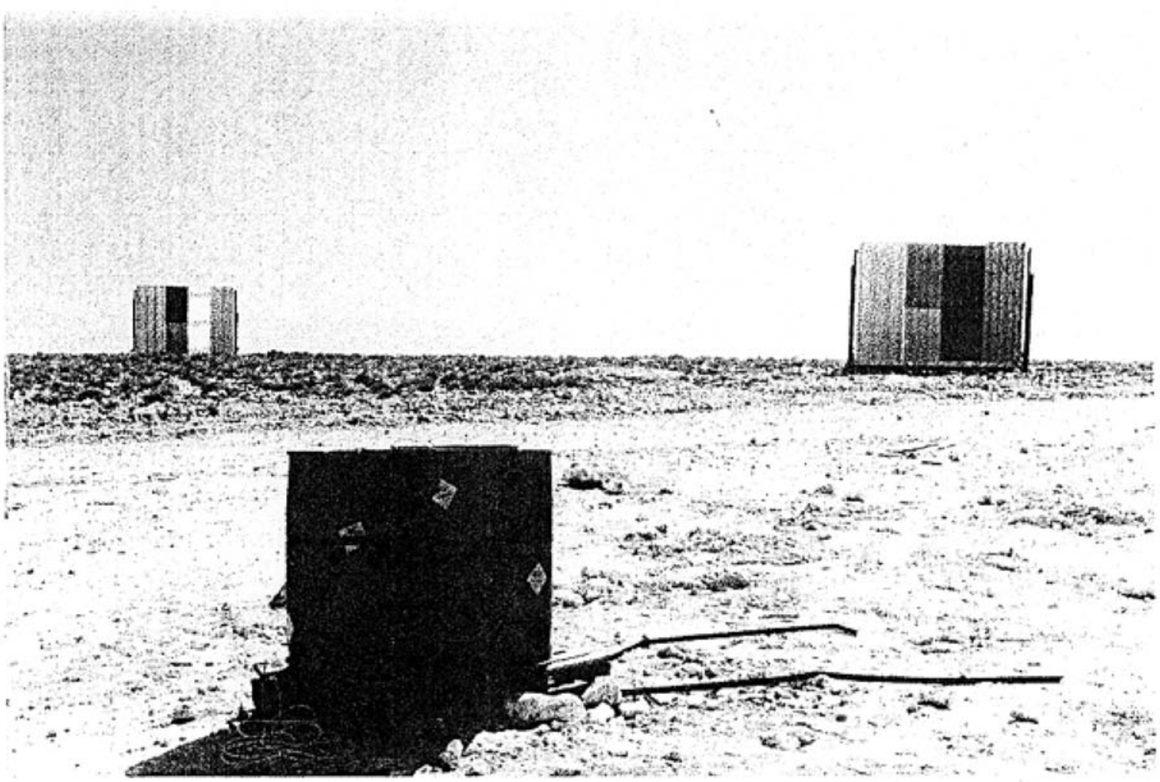
Picture 1: Wall panel 10m from C.O.E.

PICTURE 2.: WALL PANEL 20M FROM C.O.E.



Picture 2: Wall panel 20m from C.O.E.

PICTURE 3.: WALL PANEL 35M AND 67.5M FROM THE C.O.E. AND THE CHARGE EXPLOSIVE

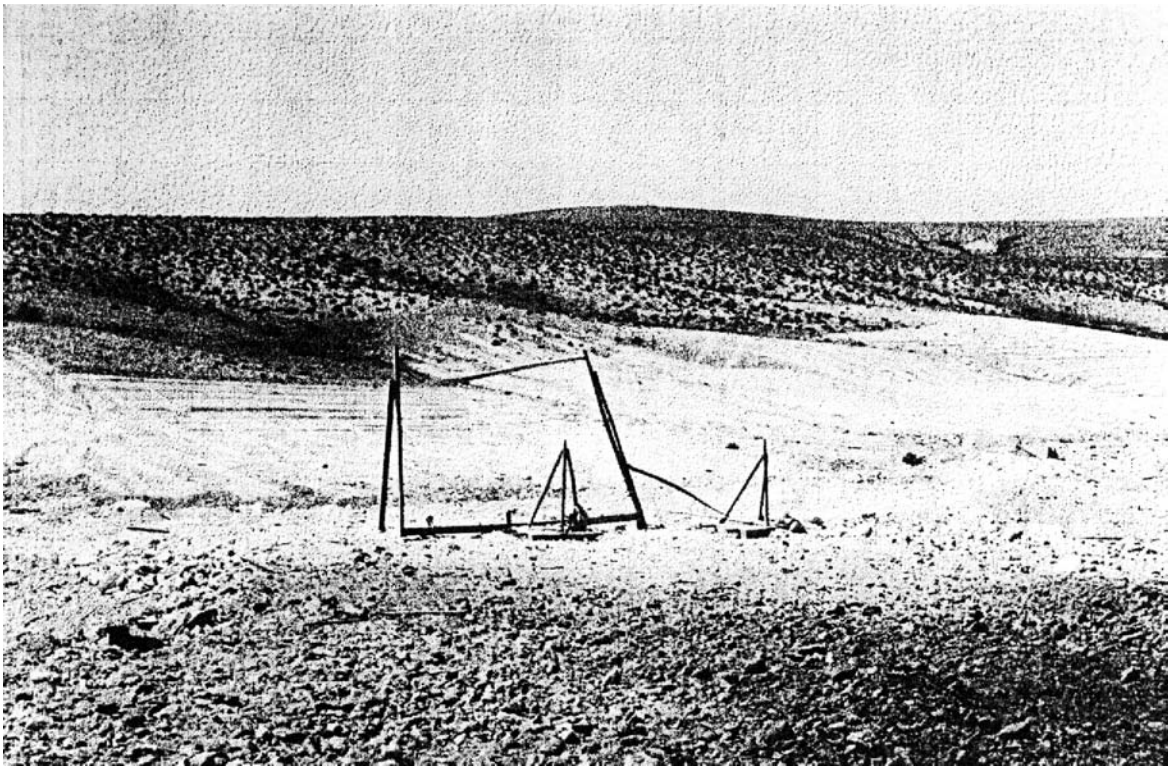


Picture 3: Wall panel 35m and 67.5m from the C.O.E. and the explosive charge.

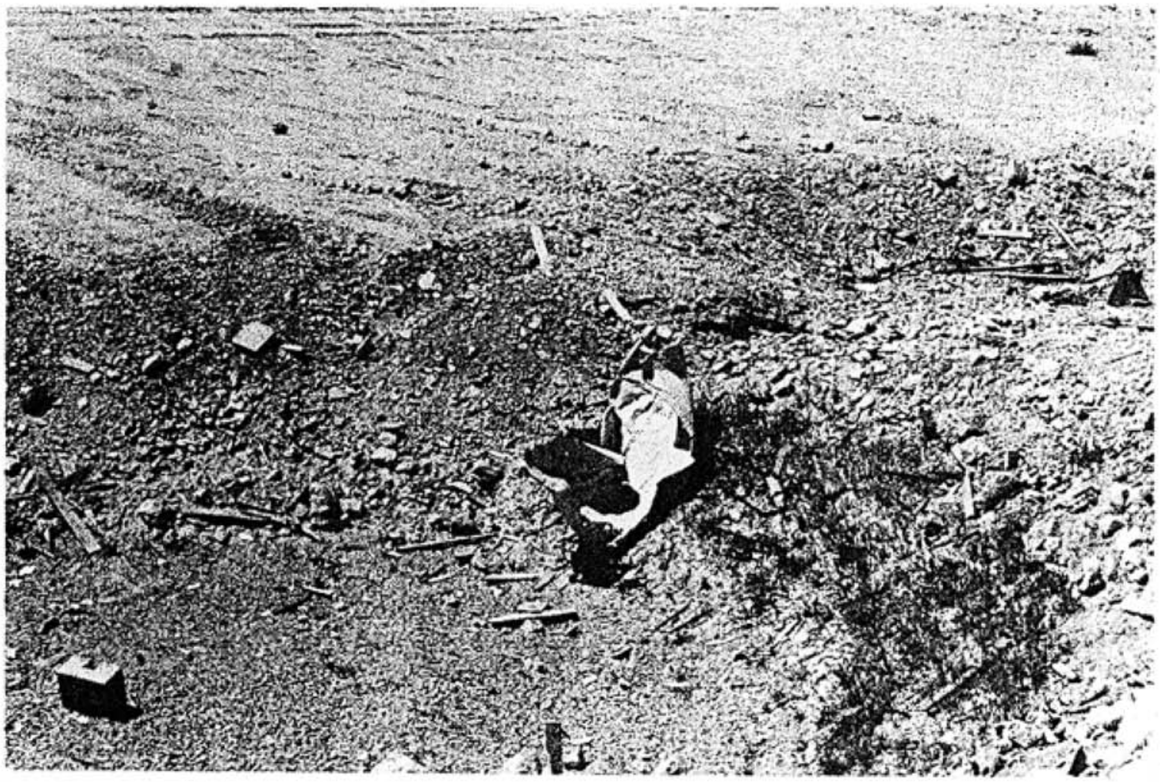
PICTURE 4.: METAL FRAGMENT FROM THE 10M WALL PANEL.

Picture 4: Metal fragment from the 10m wall panel.

PICTURE 5.:
WALL PANEL 20M FROM C.O.E. AFTER THE EXPLOSION

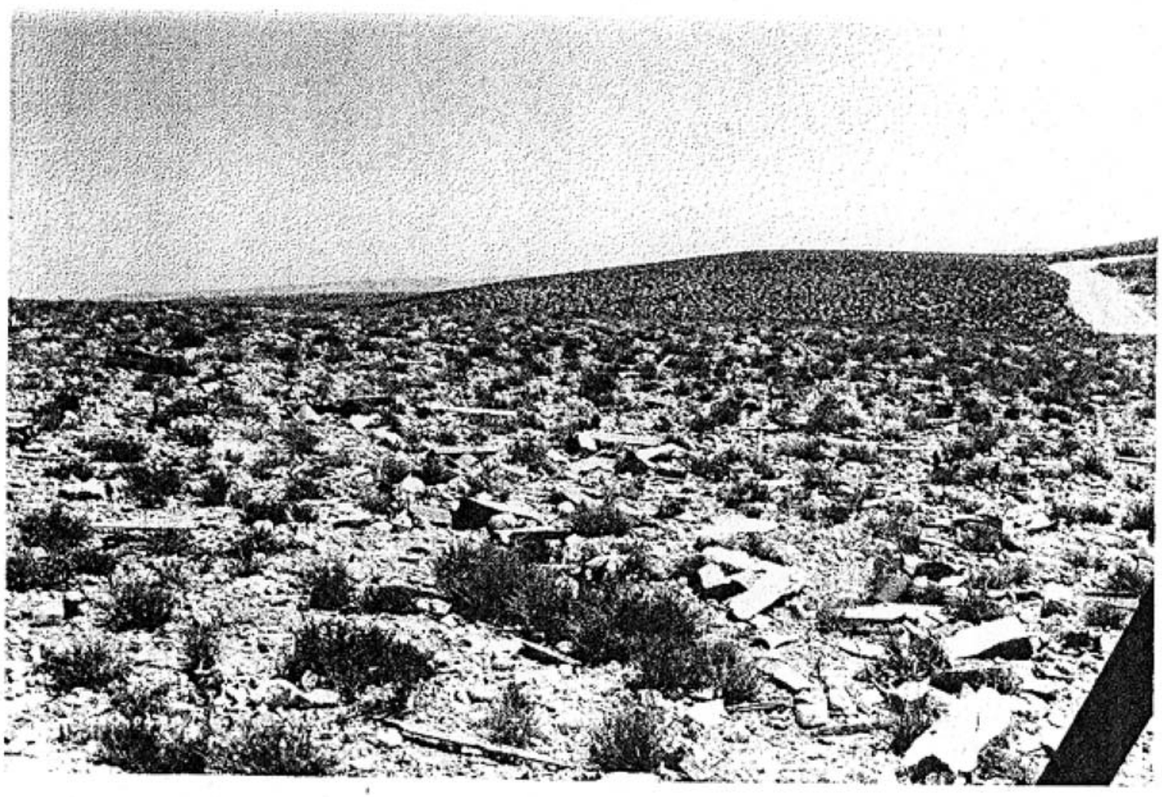


PICTURE 6.:
METAL SHEET 27M FROM WALL PANEL, 20M FROM C.O.E.



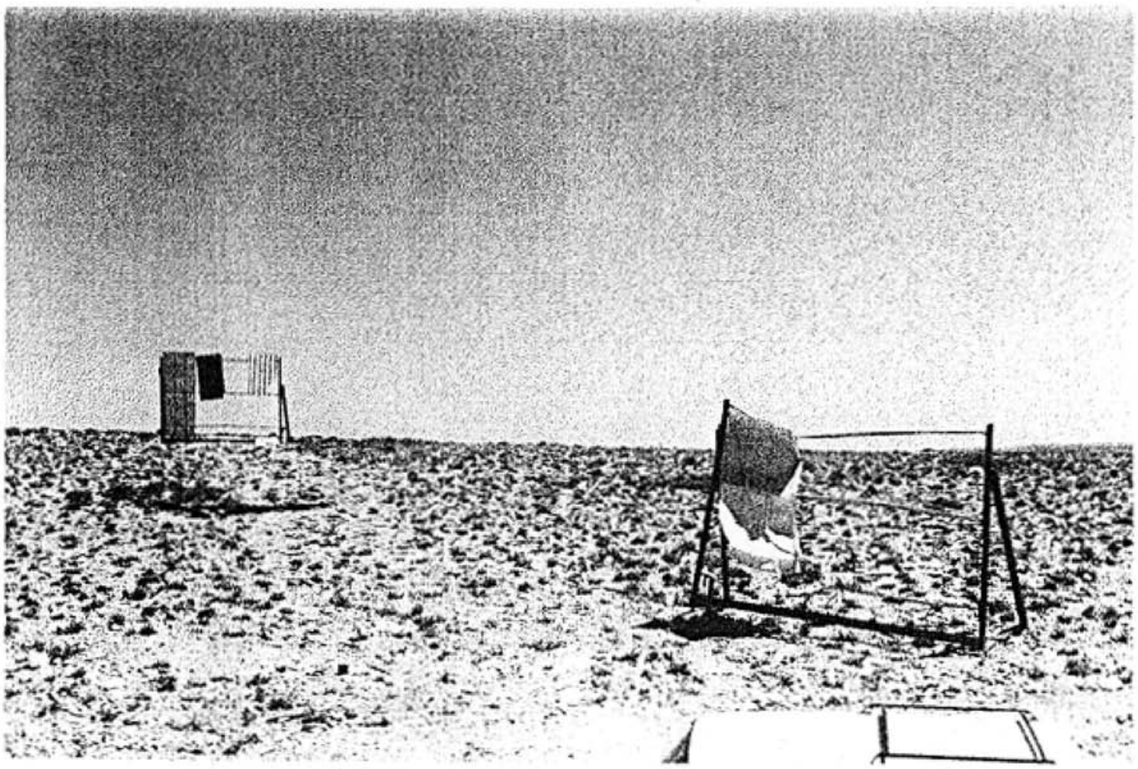
Picture 6: Metal sheet 27m from the wall panel, 20m from C.O.E.

PICTURE 7.: FRAGMENTS DISPERSAL FROM THE WALL PANEL 35M FROM C.O.E.



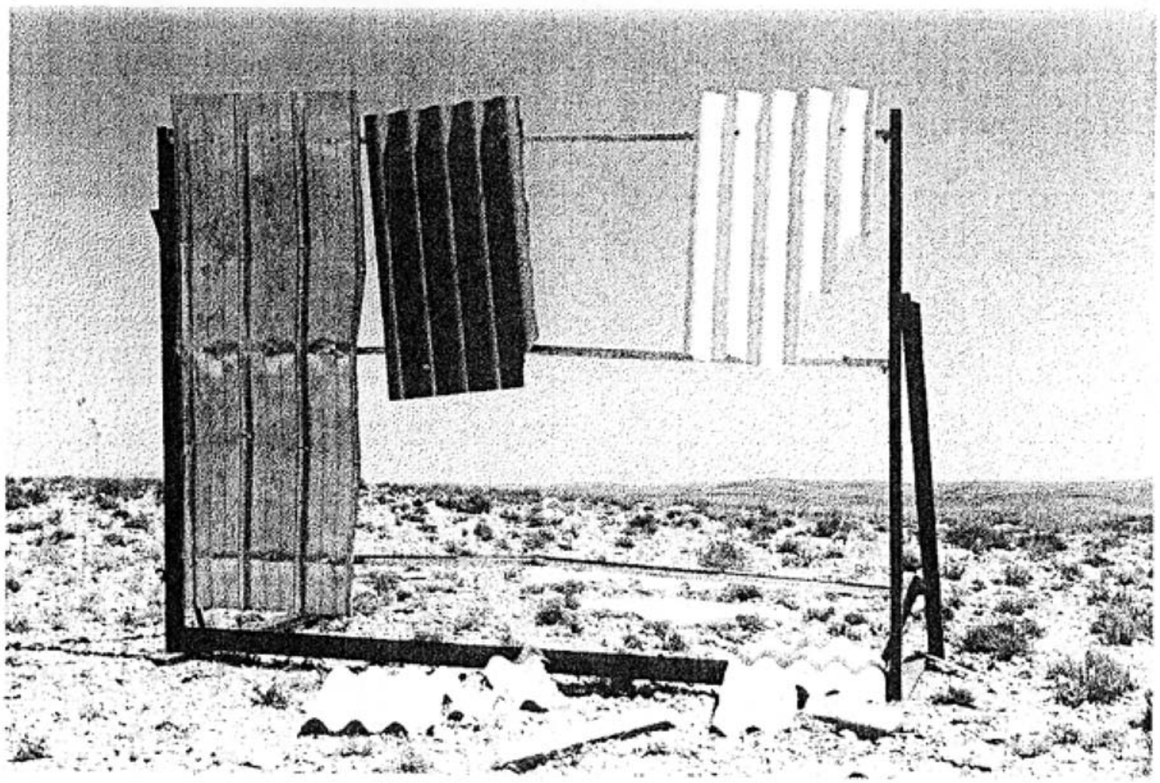
Picture 7: Fragments dispersal from the wall panel 35m from C.O.E.

PICTURE 8.:
THE 35M AND 67.5M WALLS FROM C.O.E., AFTER THE EXPLOSION



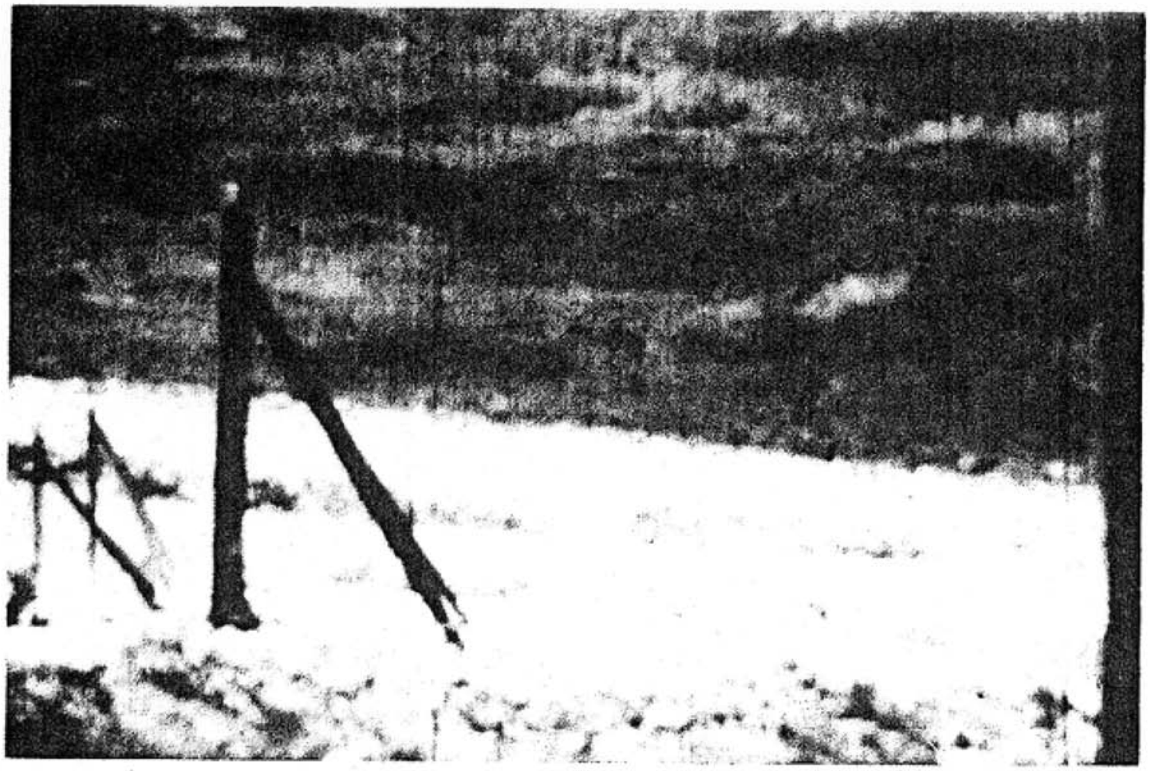
Picture 8: The 35m and 67.5m walls from C.O.E., after the explosion

PICTURE 9.:
67.5M WALL PANEL FROM C.O.E. AFTER THE EXPLOSION



Picture 9: The 67.5m wall panel from C.O.E after the explosion

PICTURE 10.: THE 20M WALL PANEL PRIOR TO THE EXPLOSION (HIGH SPEED CAMERA)

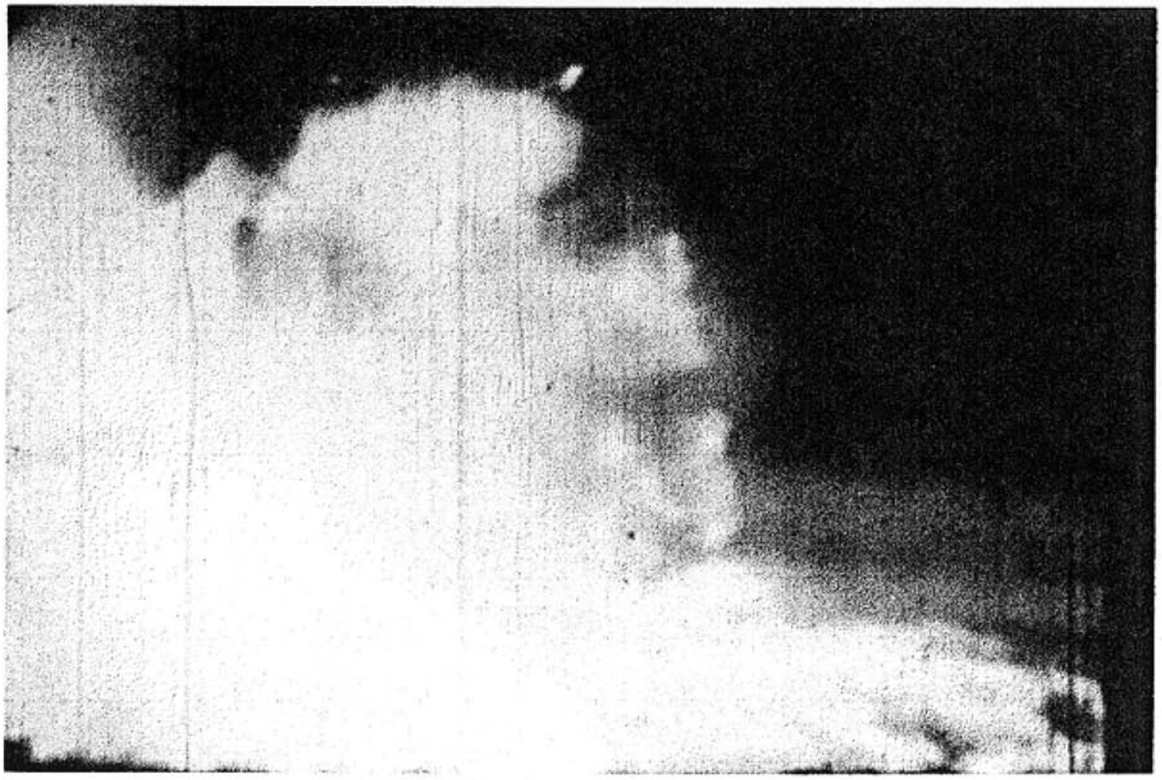


Picture 10: The 20m wall panel prior to the explosion (high speed camera)

PICTURE 11.: 10 MSEC AFTER EXPLOSION (HIGH SPEED CAMERA)

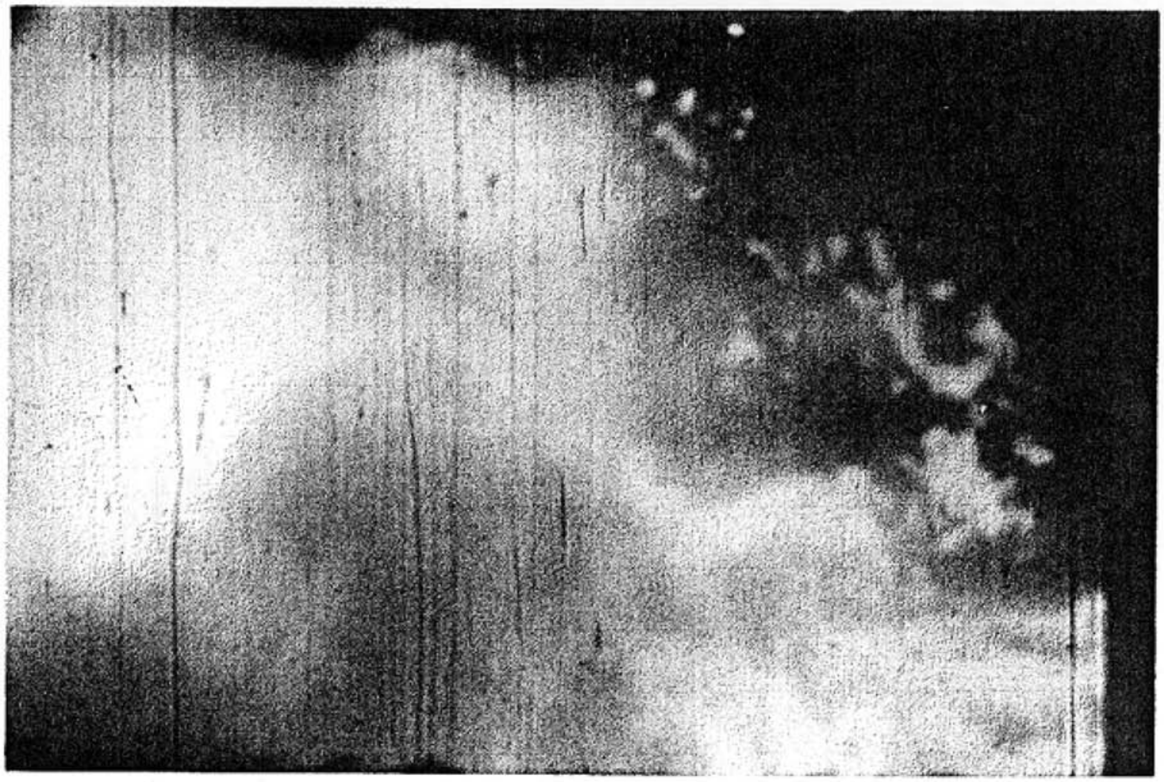
Picture 11: 19 msec after the explosion

PICTURE 12.: 30 MSEC AFTER EXPLOSION



Picture 12: 30 msec after the explosion

PICTURE 13.: 42 MSEC AFTER THE EXPLOSION
(HIGH SPEED CAMERA)



Picture 13: 42 msec after the explosion
(high speed camera)

PICTURE 14.: 59 MSEC AFTER THE EXPLOSION

Picture 14: 59 msec after the explosion